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AIR LIQUIDE ENGINEERING TECHNICAL COMMISSION	DESIGN SAFETY RECOMMENDATION	DSR B.02.04 (0) Page : 1/62

DESIGN REQUIREMENTS FOR GASEOUS OXYGEN PIPING

Supersedes :

Summary :

Many engineering materials which are considered "non flammable" may burn fiercely in oxygen. This document intends to serve as minimum safety requirements for the safe design of gaseous oxygen piping systems.

Issue	Date	Modified Pages	Remarks
0	07/03/02	Creation	

Prepared by : ETC, JY Lehman On March 07, 2002 Visa : Approved by : C Puech On : June 4th, 2002 Visa :	**Reading committee :** H Barthélémy, J Buil, J Campbell K Dunleavy, E Fano , JJ Talbot+ standard attached list **Owner :** Engineering Technical Commission
File : DSR-B02-04-(0)	Enforced on : July the 1st, 2002

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DESIGN REQUIREMENTS FOR GASEOUS OXYGEN PIPING

FOREWORD

Subject to any and all applicable national and local laws, rules and regulations, the following recommendations apply to all new installations. To the extent that national and local laws, rules and regulations are less restrictive, consideration should be given to the practices listed in this DSR.

1 PURPOSE

The recommendations contained herein give the minimum standards necessary for the design of new gaseous oxygen pipeline. It has been developed within the context of the Large Industry activity.

The worst accident taken into consideration is an oxygen fire leading to a loss of containment and potential injury in presence of personnel.

Therefore the DSR presents rules for:

- The selection of materials (metallic and non-metallic);
- The design of equipment with regard to its functionality;
- The architecture and installation of oxygen piping systems for industrial applications.

These recommendations are in addition to the General Engineering Practices for Gas Pipelines Under Pressure and only relate to oxygen.

2 FIELD OF APPLICATION

This recommendation applies to the design of all new gaseous oxygen piping systems with:

- operating pressures between 0 and 200 bar abs,
- temperatures between -40°C (1) and +100°C,
- oxygen purity up to 99.95%
- mixtures of air components above 35% oxygen for metallic material selection(2)
- mixtures of air components above 23.5% oxygen with an oxygen partial pressure of at least 1 bar for cleaning and non metallic material selection (3),
- dew point below -40°C,

This recommendation is not intended for the following applications :

- Barriers design
- Liquid (or cryogenic) oxygen
- Piping inside cold boxes and heat exchangers manifolds
- Compressors in oxygen service (including associated piping inside protective walls)
- Oxygen cylinder filling plants and breathing mixtures
- Hospital medical oxygen piping installations
- Piping on specialized equipment (such as jet piercing…)

All Air Liquide Engineering subsidiaries, divisions and construction shops, including their sub-contractors must follow to the minimum standards set forth in this DSR for all new facilities.

For breathing gases, there are additional requirements to be followed that are not covered by this document.

(1) limits of materials for low temperatures to be respected (-20°C in European standards and -29°C in US standards)

(2) Carbon steel rods (1/8") did not burn in 40% oxygen atmosphere by promoted combustion test up to 5000 psi g (344 bar g) (including in flowing conditions; refer to ASTM STP 1040 p. 51 & 188, ASTM STP 1197 p.109 and ASTM STP 986 page 100). Therefore the sustained combustion of a metallic material can be considered as very unlikely at oxygen purity below 35% but melting may be possible by kindling chain (ignition by particles, organic pollution or non metallic material; refer to ASTM STP 986 page 368). This ignition mechanism is covered by special requirements related to cleaning and non-metallic material selection for oxygen purity above 23.5%.

(3) Refer to section 10.1.2 for pipe material selection. The value of 23.5% is in accordance with new EIGA/CGA and US rules. Partial pressure limitation enables to continue the current practice to accept vaporized rich liquid in pre-purification regeneration circuits, without specific precaution for cleaning, even if the circuit design pressure is higher, knowing that this higher pressure will normally be reached with air only.

3 REFERENCES

CGA.G4.4(2)	Industrial Practices for Gaseous Oxygen Transmission and Distribution Systems
EIGA DOC 13/82(2)	Transportation and Distribution of Oxygen by Pipeline.
ASTM G88	Standard (1) Guide for Designing Systems for Oxygen Service
ASTM G94	Standard (1) Guide for Evaluating Metals for Oxygen Service
ASTM G63	Standard (1) Guide for Evaluating non-metallic Materials for Oxygen Service
ASTM G124	Standard (1) Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres
ASTM G128.	Standard (1) Guide for Control of Hazard and Risk in Oxygen-Enriched Systems
ASTM MNL36	Safe Use of Oxygen and Oxygen Systems
ASTM STP 1197	Flammability and Sensitivity of Materials in Oxygen-enriched atmospheres
ASTM G93	Cleaning methods and Cleanliness Levels for Materials and Equipment Used in Oxygen-enriched atmospheres
CGA G4-1	Cleaning Equipment for Oxygen Service
BAM List	Liste der nichtmetallischen Werkstoffe geprüft für den Einsatz in Sauerstoff (updated every year)
AL-RTS A04.01	Non metallic Materials for Oxygen Service
AL-DSR-B02.03	Oxygen Gaseous Venting to the Atmosphere
AL-NI-A.01.01	Oxygen Compatible Lubricants

AL-NI-A.01.02	Reaction of Non metallic Materials in Oxygen (excluding lubricants)
AL-NI 432	Cleaning of transportation pipelines (Reinhart process)
AL- SP-X010	Cleaning management of piping and ancillary components
AL-TS.273.01	Ferritic Steel Piping Internal Treatment
AL-CS.274.01	Cleaning, Degreasing and Cleanness Inspection of Equipment
CGA G-4.6	Oxygen compressor Installation and Operation Guide
EIGA 33	Cleaning of Equipment for Oxygen Service

(1) The ASTM standards related to Oxygen are gathered in a single ASTM publication "Flammability and Sensitivity of Materials in Oxygen-enriched Atmospheres" (Publication Code Number PCN: 03-704097-31)

(2) These two documents (CGA G4.4 93 and EIGA 13:82) are currently under revision. A common CGA/EIGA document should be issued in 2002. The DSR has contributed to the elaboration of the EIGA/CGA Working Group document and vice-versa.

To the extent that the recommendations set forth herein are inconsistent with any of the above references, the recommendations set forth herein shall prevail unless otherwise required by law.

4 DEFINITIONS - ABBREVIATIONS

Auto-ignition temperature (AIT) is the temperature at which the material ignites spontaneously in pure oxygen at a standard pressure (e.g. 120 bar as per ISO-11114-3).

Barrier:

1 Physical item such as a protective shield or wall intended to prevent flames, molten metal, and piping fragments from injuring personnel and damaging adjacent equipment in case of a fire within the oxygen system.

2 Measure or system used to prevent the occurrence of an event.

Fire barriers are screens or shields that protect personnel from injury or adjacent equipment damage. They shall block and contain an oxygen combustion lance caused by an oxygen fire where metal is a combustion fuel. Fire barriers are not intended to perform as fragment containment barriers.

Fragment barriers are blast containment barriers that perform as a fire barrier as previously defined, but also block and contain any blast fragments.

Exemption materials are materials which are considered as "nonflammable" for pressures up to 200 bar (2900 psi), (typically copper, nickel and Cu/Ni based alloys), whatever the thickness is (above 1mm). Refer to Class A in table "Oxygen compatibility of metallic alloys".

Exemption pressure[1] of a metal is the pressure below which the material is considered as self-extinguishing for any velocity or turbulence. The exemption pressure of a metal is a function of the temperature. Values given in this document are only valid between –40°C and +100°C.

Combustion resistant materials are exemption materials or metals used below their exemption pressure

Flow friction is an ignition mechanism of a non metallic material by fluid friction caused by a small leak

Gaseous Oxygen means dry gas that contains at least 23.5% (1) oxygen by volume, with the balance of the components assumed inert (mainly nitrogen or rare gases…)

(1) recommendations for metallic material selection to be applied above 35%

Impingement area: location where the main flow is directed at an angle against the component surface.
This is linked to particle impact.
(*Impinge = To strike especially with a sharp collision*)

Isolation valves are always positioned either fully open or fully closed. (They can be either manual or automatic). They are not intended to and should never be operated in any intermediate throttling mode

Oxygen index is the minimum concentration of oxygen in a flowing mixture of oxygen and nitrogen that will just support flaming combustion at atmospheric pressure (used for solid non-metallic material).

Oxygen piping system means all the stationary equipment in contact with gaseous oxygen used for its transportation and distribution. It includes pipes, fittings, valves, filters, strainers and instrumentation.

Promoted ignition test is a standard test method to determine the pressure at which a metal is flammable in oxygen (ref. to ASTM STP 1111). (see more details in APPENDIX C)

Stainless Steel (or "SS") in this document means ASTM type 304.. and 316.. grades or chemically equivalent.

Soft seat or soft gasket means valve trim polymers which are approved for oxygen service (such as: PTFE(Teflon®), PCTFE(KEL-F® or equivalent), or FKM (Viton®)).

Threshold pressure is the minimum oxygen pressure required to support self sustained combustion in reference to Promoted Ignition Test. see more details in APPENDIX C

Throttling valves can be **operated** in intermediate position under flow conditions. (Valves used to pressurize an oxygen system are also throttling valves). This includes self contained regulators.

Velocity is the mean gas velocity in the piping (i. e. actual volumetric flow divided by the pipe cross section).

A French translation of all these words is given at the end of this DSR .see APPENDIX B

[1] This definition is slightly different from the term used in the CGA/EIGA document: "Exemption pressure is the maximum pressure not subject to velocity limitation in high purity oxygen where particles impingement may occur."

5 BASIC CONCEPTS AND GUIDELINES

5.1 GENERAL

Safe operation with oxygen can be enhanced by understanding the following basic concepts:

1. Oxygen can react with nearly all materials that are not fully oxidized
2. The major hazards of gaseous oxygen are the possibilities of intense fires or explosions
3. Equipment, buildings and clothing may readily ignite and burn in an oxygen-enriched atmosphere.

Some materials that can react violently with oxygen are oil, grease, asphalt, hydrocarbon fuels, cloth, wood, paint, tar and dust. Almost any material can burn. Many materials which are generally regarded as fire-proof or fire resistant (for example stainless steel, PTFE or silicones…) can burn easily under a high enough oxygen purity or pressure.

5.2 COMBUSTION PARAMETERS AND MECHANISMS

Oxygen, fuel and a source of ignition (heat) must be present to start a fire.

Since oxygen and combustible materials are usually present, it is necessary to understand the factors that are a potential source of ignition or which aggravate the propagation.

The oxygen system designer will then minimize any environment that enhances fire, and maximize the use of materials that resist ignition and combustion.

5.2.1 TEMPERATURE

The risk of ignition increases with temperature. The main factors that favor ignition when temperature increases are :

- Less additional energy required to reach ignition point[2], which causes a higher combustion rate (higher temperature reached)
- Less heat removed by the gas flow
- Easier ignition of particles.

Operating a system at higher temperatures, (whether locally or globally) increases the probability and consequences of a fire.

5.2.2 PRESSURE

When pressure increases, usually the Auto Ignition Temperature of the materials decreases, and he combustion rates increase.
Operating a system at higher pressure increases the probability and consequences of a fire.

[2] The higher the temperature, the smaller the margin to the AIT

In oxygen enriched air mixtures, the partial pressure of oxygen is to be considered: rules applicable for pure oxygen at a given pressure P can be used for a gas mixture containing oxygen at a partial pressure equal or below P provided that other components are inert gases (non oxidizing/ non flammable gases).

(For example: rules for pure oxygen at 10 bar are applicable to 35% O2 enriched air at a pressure of (10/0.35) ≈ 28 bar)

5.2.3 Concentration

As oxygen concentration increases, there is a gradual increase in the intensity of a potential reaction. It is difficult to determine from what oxygen content the selection criteria suitable for 'bxygen" should be taken. Refer to section 2 Field of Application for selected threshold concentrations. It is conservative to use partial pressure as shown in §5.2.2 because of the mitigating effect of the inert gases[3].

5.2.4 Contaminants

Contaminants may be liquids, solids or gases which can be present in the system because of inadequate initial cleanliness, introduction during assembly or service life (blowing, blanketing...), or generation by abrasion, corrosion, flaking... Many contaminants are highly flammable and readily ignitable, due to their high surface/volume ratio (for example: hydrocarbons or oil aerosols, cleaning agents...). Their Auto Ignition Temperature is much lower than for bulk materials. Burning contaminants can promote the ignition of bulk materials: this mechanism is called kindling chain.

Potential sources of humidity should be monitored (in particular downstream water cooled oxygen compressor) as water will generate particles.(see Particle impact below).

5.2.5 Particle impact

Collisions of inert or ignitable solid particles entrained in the stream are associated with potential ignition. (Inert particles may tear away metal and other ignitable particles from the piping system)

Displacement of particles is due to velocity variations in course of time (flowrate or stream direction), or due to the geometry (e.g. changes in pipe size). During variations of the operating conditions, particles move from one dust trap to another. Incidents due to impingement generally occur during flowrate variations.

Given that absolute removal of particles is not possible (and systems can self-generate particles), the system must be designed to tolerate at least some particle presence. (see section 9.3 Filters)

5.2.6 Adiabatic compression

Rapid filling of an oxygen line from one pressure level to another will result in a temperature increase of the oxygen gas within the line due to adiabatic compression. Lines should be pressurized slowly to minimize this temperature rise.

[3] However it must be noted that the mitigating effect varies from an inert gas to another.

The potential increase in temperature as a result of adiabatic compression can be determined by the following equation :

$T_{final} = T_{initial} (P_{final} / P_{initial})^{(k-1)/k}$

Where $T_{initial}$ = Initial temperature in K T_{final} = Final temperature in K
$P_{initial}$ = Initial pressure in bar abs or in psia P_{final} = Final pressure bar abs or in psia
$k = C_p/C_v = 1.4$ for Oxygen

Therefore, for Oxygen: $T_{final} = T_{initial} (P_{final} / P_{initial})^{.286}$

By using this equation, the temperature increase due to adiabatic compression can be determined. If T_{final} computed with the above formula exceeds 260°C (500°F), then the use of a slow pressurization or equalization valve is required[4].

For example, the final temperature due to adiabatic compression theoretically reaches 260 °C (500 °F) when the initial temperature and pressure is 38 °C (100 °F) and 0 bar g (0 psig), respectively and the final pressure is above 7.5 bar g (100 psig). In such cases, a method must be provided to allow slow pressurization of the piping (see section 11.3.2) or the piece of equipment downstream must have been validated by adiabatic compression test.

5.2.7 OTHER MECHANISMS

Many other factors are recognized as causing fires:

Friction between two surfaces can produce heating and can generate particles.

Electric arc may occur from lightning, electrical cables ruptures,…

Flow friction phenomena due to leaks through non metallic materials (gaskets or valve seats).

Static discharge may occur in high fluid flow, between parts not electrically bonded.

Resonance phenomena (acoustic oscillations within resonant cavities) can cause rapid heating with high gas velocities especially where particles are present (see section 11.2.3).

5.3 GENERAL SAFETY PRINCIPLES

Ignition of materials in oxygen can be minimized by the respect of the following basic rules:

1 Select materials proved to be suitable in oxygen service : self-extinguishing materials or materials having high ignition thresholds. (see section 6)

2 Limit flow velocities under safety thresholds so as to avoid sources of energy which could initiate a fire (Particle impact, uncontrolled elevation of temperature by adiabatic compression or gas vibration). (see section 7)

3 Design for system cleanliness, clean thoroughly, and maintain this cleanliness :
Avoid dead end, low points and cavities likely to accumulate particles. Design branch connection or bypass lines so that they should not tend to accumulate particles.
Remove all contaminants which may react easily, such as oil, grease, and organic materials.
Dry and remove water in order not to generate rust.

[4] PTFE and PCTFE begin to decompose at 200 to 300°C (400 to 600°F).

Avoid presence of dust or particulate matter which, due to friction and/or impact, may react with oxygen and/or eventually may ignite the material of construction. (see sections, 9.3, 13.1 and 13.2)

4 Safeguard personnel and equipment by installing barriers where necessary and/or remote operation of valves. (see sections 8 and 10)

5 Develop suitable instructions : construction, erection, commissioning and operating with oxygen equipment requires specific construction and operating instructions, as well as specific qualification and training. Specific operating instructions must be issued by the designers for each facility, including spare parts requirements.

6 Use validated equipment: see appendix D

7 Perform safety review : Oxygen system design and operating instructions shall be subject to an independent safety review (to be developed).

8 Use only qualified technical personnel, experienced or trained in construction, erection, commissioning, operation and maintenance of oxygen systems, and adopt specific operating practices for oxygen.

6 OXYGEN COMPATIBLE MATERIALS

6.1 GENERAL

The oxygen compatibility of a material may be defined as its ability to co-exist with both oxygen and a potential source of ignition.

Selection of

Although there is no absolute classification, the main properties of a material for oxygen compatibility are:

- A high auto-ignition temperature (AIT) (for non metallic materials)
- A high exemption pressure (for metallic materials)
- A low heat of combustion
- A high mass thermal capacity
- A high thermal conductivity
- A high oxygen index

Other parameters may have a decisive importance such as thickness.

Materials selected for oxygen service must be chosen from lists of materials previously tested and approved, for instance:

- Two ASTM standards cover this material selection problem: ASTM G94 for metals, and ASTM G63 for non-metallic materials.
- The BAM in Berlin publishes each year a list of non-metallic products tested in accordance with German regulations VBG.62.

Air Liquide's CTE (Centre Technique d'Expertise) in Blanc-Mesnil can test materials or devices for oxygen use (see AL-RTS A04.01, NI-A.01.01 and NI-A.01.02)

6.2 METALLIC MATERIALS

Selection of metallic materials for oxygen compatibility is to be respected above 35 % O2

6.2.1 GENERAL

Although the oxygen compatibility of a material depends on the considered mechanism (particle impact, friction/rubbing, promoted ignition...), it is possible to classify usual materials according to their oxygen compatibility ratings:

In the following table, materials are given in decreasing "promoted ignition" rating. (ref. to ASTM STP 1197 page 7 and EIGA/CGA working group).

This classification must be considered as relative only. Oxygen compatibility can be classified as follows in the table: A = Very High ; B= High; C = Medium ; D = Low.

Material selection recommended by this document has been achieved according to ASTM G94

Exceptions to referenced selection of material for concerned specific use in oxygen service must be approved by a specialist.

For a better understanding of "**threshold pressure**" and "**exemption pressure**" concepts, see APPENDIX C

Oxygen compatibility of metallic alloys (Table in SI units is in Annex)

Material (UNS Number)	**Particle impact**	**Friction Rubbing**	**Promoted Ignition**	Threshold abs pressures psi 0.125" dia (6)	EIGA/CGA Exemption pressures psig 0.125" dia (6)	AL Exemption Pressures psig 0.125" dia (7)
NICKEL 200	-	A	A (2)	> 8000	3000 (1)	3000 (4)
NICHROME V	-	-	A (2)	-	3000 (1)	
MONEL 400	A	A	A (2)	> 10000	3000 (1)	3000 (4)
MONEL K500	A	A	A (2)	> 10000	3000 (1)	3000 (4)
NAVAL BRASS (C46400)	-	-	A (2)	> 10000	2000 (1)	
COPPER			A (2)	> 8000	3000 (1)	3000 (4)
90-10 CUPRONICKEL (C70600)	-	-	A (2)	-	3000 (1)	2000
70-30 CUPRONICKEL (C71500)	-	-	A (2)	-	3000 (1)	2000
FREE CUTTING BRASS (C36000)	-	-	A (2)	-	2000 (1)	
BERYLLIUM NICKEL	-	-	A (2)	-	-	
2% BERYLLIUM COPPER (C17200)	-	-	A (2)	> 10000	2000 (1)	
ADMIRALTY BRASS (C44300)	-	-	A (2)	-	2000 (1)	
RED BRASS	-	-	A (2)	> 7000	2000 (1)	
TIN BRONZE (Gun Metal)	A	A	A (2)	> 7000	3000 (1)	2000 (4)
YELLOW BRASS	A	B	A (2)	> 7000	2000 (1)	
INCO 141 (Filler metal)	-	-	B	-	-	
INCONEL X750	-	-	B	-	1000 (1)	
INCONEL 600	A	A	B	2500	1000 (1)	
BERYLCO 440	-	-	B	-	-	
SILICON BRONZE (C65500)	-	-	B	-	-	
HASTELLOY C-276	-	B	B	3000	750 (1)	
STELLITE 6-B	-	C	B	2500	500 (1)	
MP 35 N	-	-	B	-	-	
INCONEL 625	B	-	B	-	1250	
INCOLOY 800	B	-	B	2500	750 (3)	
INCONEL 718	B	-	B / C	1000	500 (3)	
HASTELLOY X ; G3 ; G30 & B	-	B	B	-	500 (3)	
CN-7M	-	-	C	-	375	
CF 3 ; 3M ; 8 ; 8M ; CG-8M	-	-	C	-	200	
17-4 PH STEEL	-	B	C	1000	300	
Ni Resist Type D2	-	-	C	-	300	
410 SS	-	C	C	-	250	150
430 SS	-	-	C	-	250	150
13-4 SS	C	A	-	-	250	150
316 SS / 316 L	C	C	C	500	200 290 (5)	150
321 / 347 SS	-	-	C	1000	200	150
304 / 304 L SS	C	C	C	1000	200 290 (5)	150
INVAR 36	B	C	C	< 1000	-	
9% Al BRONZE (C95800)	A	C	C	250	150 (3)	
Nodular CAST IRON	B	A	C	-	50	
NITRONIC 60	C	C	C	< 500	-	

14-5 SS	C	B	C	-	-	
9% Ni STEEL	-	C	D	< 500	25 (3)	
CARBON STEEL	-	C	D	< 500	30	30
6061 ALUMINIUM Alloy	D	D	D	25	15 (3)	

(1) There is no minimum thickness (above 1mm) specified for this pressure.

(2) Known as "Exemption material"

(3) These values are not in EIGA/CGA document

(4) Upper shelf pressure higher than 5000 psig established by Static Promoted Ignition Test

(5) 290 psig at 6.4 mm thickness, 200 psig at 3.2 mm thickness

(6) The pressure values have been tested at 99.7% O2

(7) The EIGA/CGA exemption pressures have been determined in static conditions but some specific tests performed with Stainless Steel have shown that this material burns at a lower pressure under flow conditions. It has been decided to arbitrarily define conservative AL threshold values before getting validated test results.

(8) In oxygen enriched air mixtures, the partial pressure of oxygen is to be considered: rules applicable for pure oxygen at a given pressure P can be used for a gas mixture containing oxygen at a partial pressure equal or below P provided that other components are inert gases (non oxidizing/ non flammable gases).

6.2.2 EXEMPTION MATERIALS

Copper, Nickel, and alloys based on them (Monel, Cupro Nickel, Tin Bronze…) show very good oxygen compatibility. Their use is permitted at all velocities for pressures below 200 bar. They are qualified as "exemption materials".

Nickel and Tin-bronze are the only base metals that would not burn in oxygen when in form of very small diameter wire (typically less than 0.1 mm). Therefore, nickel is the preferred material as a wire for screen fabrication (for weld ability).

In case of bronze alloys, the maximum permitted aluminum content to be classified as "copper alloy" is 2.5%.

6.2.3 STAINLESS STEEL

Austenitic stainless steels tend to resist propagation of a flame at moderate oxygen pressure (tested exemption pressure for 3.2 mm diameter rods is 200 psig), even when subjected to a strong initiator, provided that the wall thickness exposed to oxygen is equal to, or greater than 3.2 mm (1/8").

Stainless steel pipe which is less than 3.2 mm (1/8") thick will be treated as carbon steel from the standpoint of oxygen compatibility. (Note that sintered SS behaves like powder, and is thus forbidden, (except for O2 high purity systems, where a very low filtration level is required. See Filters section 9.3.3)

6.2.4 CARBON STEEL

Carbon steels resist propagation of a flame up to 3 bar abs. However carbon steel is usually preferred for dry oxygen piping, based on ignition prevention steps (velocity limitation; cleanliness…), considering that no significant corrosion appears with dry oxygen.

Note: The fact that austenitic stainless steels propagate combustion less well than carbon steels is an outstanding exception to the general principle given in section 6.1 (SS thermal conductivity < CS thermal conductivity)

6.2.5 Aluminum and Aluminum Alloys

Aluminum and aluminum based alloys burn even at atmospheric pressure in oxygen. They burn very rapidly with a high release of energy. For this reason aluminum is forbidden for the scope of this document.

Aluminum alloys are used in cryogenic process, cylinders and atmospheric heaters, based on prevention of ignition mechanism [5]. This use is not in the scope of this document.

Aluminum bronze (around 10% Al) is comparable to austenitic stainless steel as regards combustion with O2.

6.3 NON METALLIC MATERIALS

Parts made of non-metallic materials, (for example: gaskets, valves seats..) are generally more flammable than metals, and shall have the minimum possible mass. These materials shall be dense, non porous and free from surface of other defects. They should be preferably reinforced by a metallic structure.

Fully oxidized products present a good oxygen compatibility, also graphite (stable structure of carbon).

The selection of these materials is based on experience and testing of impact, ignition and flammability characteristics (oxygen index). (It could be useful to consult the document ASTM G.63).

To assess the oxygen compatibility of a non metallic material, the main parameters to be considered are its Auto-Ignition Temperature (AIT) and its Heat of Combustion.

Note that the Auto-Ignition Temperature often depends on the method of manufacture, and on the additives used.

It is also important to check the behavior of the product in oxygen atmosphere at the maximum working pressure and temperature.

Therefore these materials should be used only if previous tests have proved them safe to use. Non-metallic materials must be assessed on their compatibility with oxygen by BAM in Berlin, CTE in Blanc-Mesnil, or an equivalent official laboratory. (Ref to AL-NI.319 for more details).

6.4 LUBRICANTS

Lubricants are usually potential source of ignition with gaseous oxygen.

All components should be designed to function without lubrication. However, if a lubricant is necessary to permit assembly operations or the functioning of a component, it shall be selected from the lubricants listed in the relevant documents from EIGA, CGA, BAM ("BAM-Liste der nichtmetallischen Werkstoffe"), or AL-NI A.01.01, or any contact between oxygen and the lubricant must be impossible per design.

The lubricant shall be incorporated for life when the component is assembled, and its use shall be kept strictly to a minimum. No trace shall be discernible from the outside.

[5] alumina (i.e. aluminum oxide) is an effective protective layer against ignition provided that its integrity is not affected (by shocks, impacts, scratches…)

7 VELOCITY LIMITATION FOR PIPING MATERIAL

7.1 HISTORICAL ACCOUNT / STATE OF ART

From the beginning, long oxygen pipelines have been made of carbon steel. Velocity limitations have been associated to the use of this material for a long time (about 50 years) in sections where impingement can occur, including specific pieces of equipment and/or fittings (valves, tees,...). These limitations are not consistent as they were issued by different independent actors. Significant differences exist between Europe and the US for instance.

Knowledge has improved during the last 10 years and it is now possible to merge these different traditions.

See Historical velocity curves in Appendix B. The "CGA G.4.4 50%" curve is meant for impingement areas.

7.2 GENERAL

The term "velocity" refers to the maximum actual velocity in the piping, taking into account steady state operating conditions as well as transient conditions.

Whenever other materials than exemption materials are used, the velocity limitations are enforced. When an exemption material is used, there is no velocity limitation.

In any piping system, the materials should be selected on the basis of the maximum design velocity. The correct calculation of maximum velocity will use the maximum operating mass flow at the minimum pressure for a given free passage area, and at the maximum operating temperature.

Let-down valves, by-pass valves, vent valves and safety valves require specific rules (see section 9.2)

Note: Pipelines are usually sized on the basis of economically acceptable pressure drop. So design velocities are often lower than those imposed hereafter for materials selection. Main exceptions are letdown station and location subject to exceptional or intermittent operation. (This is to be checked by the designer.)

7.3 IMPINGEMENT AREAS

This document recognizes two situations:

- one when the flow is smooth, and impingement is unlikely to occur,
- and the other where high velocity and hurdles in the flow path cause wildly turbulent flow conditions and can lead to impingement. Common examples of impingement locations are where the flow changes direction abruptly:
- pressure letdown valves, vent valves and relief valves
  (impingement always occurs there, even in a straight pipe run, due to high (often sonic) velocities),

- butterfly valves, check valves…

- side entrance tees or branch feed lines
  - orifice plates
  - thermowells
  - filters and strainers …

Locations where impingement occurs are judged to be of additional hazard because past experience suggests that the impact of particles has been the cause of ignition.

In a production plant impingement may occur in many locations; therefore all parts of the piping should be considered as impingement areas.

A pipeline system usually includes two section types :

long uniform sections without velocity or directions changes
complex sections containing impingement locations : tees, elbows, flow meters, expansion or isolation valves…

these two kinds of sections may have different diameters : long ones based on trade off between capital and power cost, complex sections are rather based on safety concerns.

Long uniform sections are usually made of carbon steel, (or stainless steel for higher pressures) and are sized on velocity limits or pressure drop considerations.

Complex sections may use exemption material and may be sized on other criteria like expansion valve CV.

7.4 MAXIMUM ALLOWABLE VELOCITY CURVE

The maximum velocity for CS is limited as follows (around the "historical" point 15 bar abs 30m/s):

Under 3 bar abs : no velocity limitation except for vent pipe (see section 11.3.1)

For gas pressures between 3 and 15 bar abs : Velocity is limited to 30 meters per second.

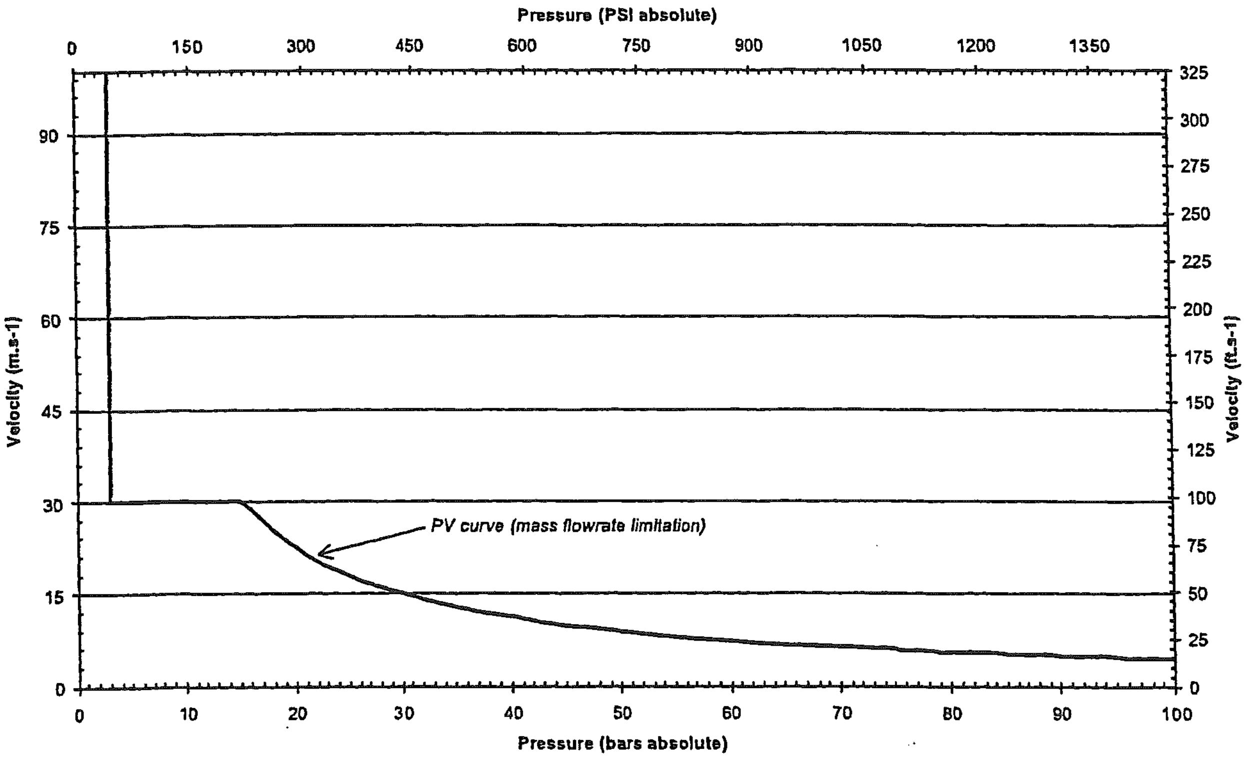
This rule is to be applied at the maximum operating temperature and minimum operating pressure.

Between 15 bar abs and 100 bar abs : The curve is based on P x v = 450, (P in bar abs, v in m/s) (flowrate independent of pressure)

From 100 bar to 200 bar, velocity is limited to 4.5 m/s

Note: Although higher velocities could be considered from the safety point of view, these conservative values have been adopted as they are usually overridden by pressure drop considerations

Overall view curve: Velocity limitation for Carbon Steel (For other materials than Carbon Steel, this curve applies above the exemption pressure.)



This curve is for: Ambient temperature and Normal dust level 100µm

8 RELATIONSHIP BETWEEN EQUIPMENT DESIGN AND SAFETY DISTANCES OR BARRIERS

8.1 GENERAL

The main hazard for personnel is an ignition through the pipe wall or the pressure envelope the consequences of which, in the absence of protections, are serious enough not to be acceptable, even with a low occurrence frequency.

Ignition mechanisms are complex. A frequent one is kindling chain starting by ignition of particles, but other ones have to be taken into consideration (mechanical failure, friction, flow friction, inappropriate organic material). As reducing the ignition probability to a very low level is hard to achieve, the real issue is combustion propagation. It is possible to assume that if there is no propagation, the consequences of an ignition will be limited[6].

The "exemption pressure" concept means that if the material is used below this pressure, fire propagation will not take place. The velocity curve deals only with the particle impact ignition probability. It does not guarantee the lack of combustion propagation (unless the pressure is below the exemption pressure).

The following basic principles can thus be adopted:

- If fire propagation is possible (thus for any material used above its exemption pressure and above the velocity limit), a remote valve control or a protective screen should be used.
- Below the exemption pressure no protection is required if the equipment has been validated for such use.
- Above the exemption pressure, velocity limitation must be respected.
- In all cases, maintenance and repair shall be performed without pressure (except for actuators of isolation valves and Daniel Senior Orifice™ Fittings where approved procedures must be used). Barriers are to be installed between equipment in service and equipment in maintenance such that maintenance personnel or operators can work safely.

8.2 BARRIER FUNCTIONS

The function of barriers is to protect people against the following feared effects :

- Projectiles (fragment barrier);
- Fire (fire barrier);
- Gas jet;
- Oxygen enriched atmosphere.

[6] Energy levels used in the promoted ignition tests are lower than those used in the AL tests (Ignition Testing of Hollow Vessels Pressurised with Gaseous Oxygen): pipe deformation due to high temperature observed during AL test occurs at higher energy levels.

Barriers must withstand pressure release during a flash-fire, forces due to the jet resulting from breaching the pipe and forces due to the impact of materials ejected.

Some safety equipment such as shut off valves may have to be protected from "domino effect".

Exposed people may be :

- the personnel who are operating the component
- the maintenance personnel working near to the component
- any others operators or third party people who would happen to be in the vicinity.

Barriers may be :

Permanent (there even if nobody is there)
Transportable (when people are likely to be there, site preparation before maintenance for example)
Individual (worn by the exposed people)

They must never increase the risk by the confinement of fire, oxygen or people.

This document only deals with permanent barriers.

Additional guidelines can be found in CGA G4.6.

9 EQUIPMENT SELECTION AND DESIGN

9.1 GENERAL

Typical components are: throttling valves, pressure reducer, isolation valves, meters, insulating joints, filters... They are made of several parts of various materials and shapes.

9.1.1 SELECTION OF EQUIPMENT

An oxygen system component **must be specially designed and validated for oxygen service,** and is not simply a "standard equipment degreased for oxygen". This validation will **be associated** with a **personnel protection level (Safety distances, fire barriers...)**, as well as requirements for the connected piping according to service conditions.

Only approved equipment can be used in oxygen piping systems.

See APPENDIX D.

9.1.2 DESIGN APPROACH

Each type of component is to be designed according to its own risk, that is to say according to the specific ignition mechanisms of its category.

Each component is reviewed from the following points of view :

ignition mechanisms;
design and maintenance requirements;

and personal protection needs

When recommended materials are not available (ei : not validated by the corporate team without barriers), a less stringent material selection may be used provided that barriers are installed to protect the operators. In any case carbon steel shall not be used above it's exemption pressure.

9.2 VALVES, CHECK VALVES AND SAFETY VALVES

9.2.1 General

This type of equipment is complex, with very variable design, and subject to many ignition mechanisms :

- high velocity flow conditions may entrain particles and their impingement on a surface,
- leaks through a non metallic material, causing flow friction,
- presence of thin metallic parts,
- friction or rubbing due to moving parts…

Consequently each item of each manufacturer must be approved by the specialist individually.

Each item is selected for a specific service. If service changes, a safety review must be performed for this new service.

Guidelines for design and validation of such equipment are given in APPENDIX D

9.2.2 Valves for throttling service

They are four types of throttling valves :

- Control valves which throttle flow, to control a process parameter
- Pressure equalization bypass valves used to pressurize an oxygen system around a block valve even when operated manually.
- Isolation valves without bypass which can be used to pressurize the downstream circuit or to cut off the downstream circuit during service.
- Purge or vent valves

In line noise attenuation devices are often incorporated in throttling valves (see section 9.8.1).

Note: A valve may have two functions (ex: pressure control and isolation) only if each function is ensured by a dedicated device. (e.g. Spheraxial™ pressure regulator)

9.2.2.1 Ignition mechanisms

Past experience shows that risk areas are not only located in the valve itself, but also in the downstream pipe especially in the first component impacted immediately downstream of the valve (elbow, orifice plate, noise reducer, tee with side entrance…).

The flow inside and downstream a throttling valve has a high velocity (up to sonic velocity). Maximum acceptable velocity for particles is exceeded. Particles may ignite and then communicate fire to downstream materials as per the kindling chain reaction. Although this is the main mechanism in throttling valves, one must not forget the other ones, which may become predominant if all the precautions have been taken against the particles impact risk.

Quick opening with low pressure downstream can lead to adiabatic compression, particle impact... The opening time of throttling valves must be controlled in order to limit downstream pressurization rates and the consequent adiabatic compression (see 9.2.2.3).

9.2.2.2 Specific requirements for downstream piping

Requirements for the downstream piping are as follows (even with a fully oxygen compatible valve):

Reducer (if any) and pipe, for a length of 8 downstream pipe diameters, shall be fabricated from a combustion resistant material at the downstream pressure.

The first elbow or bend (if less than 5 D radius), must be considered as potentially hazardous if positioned within distance of 20 D downstream the valve, and shall be fabricated from a combustion resistant material at the concerned pressure, as well as other piping elements such as tees, reducers … (see list in 7.3). (See APPENDIX F)

Requirements upstream are as follows:
Velocity limitations have to be applied, taking into consideration that the valve can be fully opened with no pressure downstream, except if flow limitations precautions are taken (for example, by means of instrumentation).

9.2.2.3 Specific requirements for manual throttling valves :

1/4 turn manual valves (plug and butterfly) must be used only with multi-turn gear actuator, except for direct venting to the atmosphere, because these valves are inherently quick opening (see adiabatic compression 5.2.6).

9.2.2.4 Specific requirements for emergency shutoff valves

Emergency shutoff valves are normally operated in the fully open position, and are closed only in the event of an excess-flow signal. They are often installed upstream a filter. Although in normal operation the valve experiences smooth flow, in the event of an excess-flow condition the valve will experience excessive velocities and momentary turbulence upon closing. They must be specifically approved for this type of service. **They must also be automated.**

Except when specifically approved for throttling service, emergency shutoff valves **should not be opened unless the pressure is fully equalized,** and oxygen is kept from flowing. Consequently, they may have to be equipped with bypass valve.

9.2.3 VALVES FOR ISOLATION SERVICE

Isolation valves are valves operated either fully open or fully closed. They are used to isolate equipment or sections of piping for maintenance or shutdown purposes. Their operation should be minimized (only when absolutely necessary). They should never be operated in any intermediate throttling or regulating mode except for pressures lower than 2 bar g (30 psig) and they should not be operated unless the pressure is fully equalized, except if they have been approved for throttling service.

An isolation valve must be equipped with a bypass (see section 11.3.2) and instrumentation to check the pressure equalization before opening the valve.

The procedure for opening and closing must be defined and permanently available near the valve. This procedure must clearly warn the operator that the valve **must never** be operated in any intermediate throttling or regulating mode except for pressures lower than 2 bar g (30 psig).

Isolation valves **must be installed with barriers** except if they are resistant to ignition mechanism(s) caused by partial opening under flow conditions (e.g. valves validated for throttling service).

9.2.4 PRESSURE RELIEF VALVES

9.2.4.1 General

Pressure relief valves are considered to be throttling valves as they usually operate in critical flow.

9.2.4.2 Ignition mechanisms

See Throttling valves

9.2.4.3 Design recommendations

Oxygen service below 2 bar g allows carbon steel downstream of pressure relief valves and vents to the atmosphere. Nevertheless pressure relief valves should be made of combustion resistant materials because of the risk of particle impact at places where local pressure is higher than 2 bar g (another consideration is corrosion due to atmospheric moisture). API 526 type should use combustion resistant materials for the nozzle and the trim and at least stainless steel for the body.

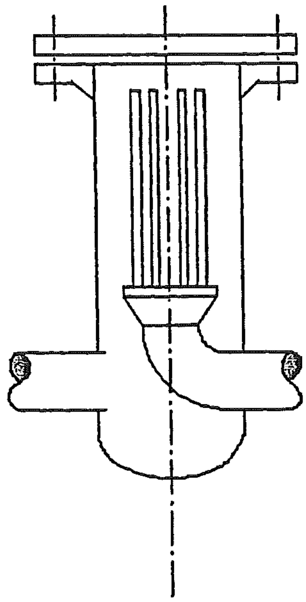
9.2.5 CHECK VALVES

Internal parts, submitted to direct impingement flow must be combustion resistant. If the check valve is soft seated it shall have oxygen compatible seat material. The body of a check valve may or may not be under impingement depending on the design.

9.3 FILTERS

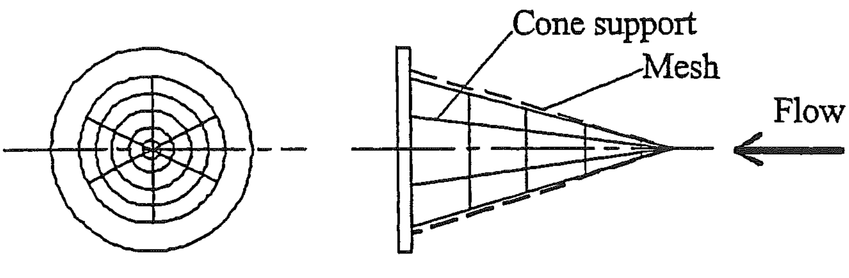
There are two main types of filters :

- pressure vessel type, with sintered bronze cartridges (20 to 50µm opening) :



This design allows a large surface area.

- flanged type, with conical screen (100 µm opening):



9.3.1 IGNITION MECHANISMS

By definition, filters are dust traps: if they are poorly designed, installed or operated, they can become a source of ignition. However experience shows that fires on filters are rare provided that the filter media is oxygen compatible.

Impacts of flying particles on the filter media can locally melt and pierce it and consequently degrade the filtering efficiency, making the protected equipment exposed to particles.

DESIGN REQUIREMENTS FOR GASEOUS OXYGEN PIPING

The most frequent incident is the rupture of the filter itself due to the differential pressure, which sends broken pieces in the piping downstream, or a back-flow through the filter which sends particles in the piping upstream.

Another mechanism is the ignition of a thick dust cake, which can ignite the filter shell.

9.3.2 LEVEL OF FILTRATION

The finer the filtration, the better the effect. The level of filtration depends on the requirements of the equipment to be protected (meters, machine, throttling valve…)

Upstream throttling valves, filters with a 100 µm opening screen are considered sufficient to remove the largest and most dangerous particles, without adding significant restriction to flow.

9.3.3 DESIGN RECOMMENDATIONS

Recommended filter types are :

conical screens using a 100 µm opening filter media made of Nickel (1), outside and upstream of a Monel (or other exemption materials) wire and frame support assembly. This opening can be obtained by means of twill weave[7] and 0.3 mm diameter wires.

(1) Nickel gives mechanical strength and resistance to promoted ignition by combustible particles. Tin Bronze meshes are accepted in existing plants. Monel meshes are tolerated in existing plants and should be replaced by Nickel on maintenance opportunities.

The filter is installed in a flanged pipe spool made of suitable material in accordance with the maximum allowable velocity, with the cone pointing upstream.

The element (support and mesh assembly) must:

- either be able to withstand total line pressure when completely clogged,
- or a pressure differential indicator with an alarm should be installed to protect the element. The design differential pressure must be at least half the design pressure of the pipe.

The filter should **not** be installed in vertical pipe runs if the flow is upwards (dust will fall back when flow is interrupted). An external indication should enable to check the cone orientation during service.

cartridge/separator type normally uses a 20/50µm filter media made of sintered tin bronze. Diameter of the vessel should be calculated in accordance with the maximum allowable velocity between the internals and shell.

The inlet nozzle should not have a reduced section with regard to the incoming pipe. The material of the vessel must be in accordance with the maximum allowable velocity.

Sintered and mesh SS filters **are forbidden and must be replaced.**[8]

[7] Higher mechanical strength and resistance to fusion

[8] Sintered or mesh SS filters are tolerated in Electronics UHP oxygen if a pre-filter is installed since copper is not allowed for this service.

9.3.4 Pressure drop monitoring

Differential pressure measurement devices have to be installed both for operational reasons and for dust accumulation monitoring.

9.4 INSULATING JOINTS

An insulating joint is a special flange connection which electrically isolates the underground cathodic protection system. Insulating joints may be of two types:

- **Simple standard flanged assembly** with thick insulating gasket, and bolts and nuts insulated by means of insulating tubes around the bolts and insulating washers.
- **One piece type** where assembly and tightening is done in the work shop

9.4.1 Ignition mechanisms

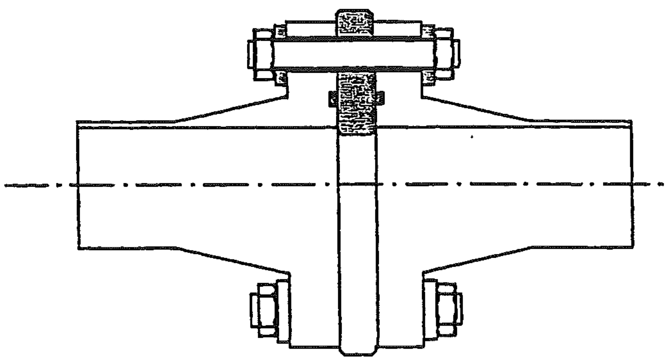
Arcing across the inner gap between electrically insulated flanges is a possible ignition source. Another mechanism may be flow friction on a gasket leak (for example due to mechanical stresses generated by underground piping deformations). The mass and the heat of combustion of the gasket may be then sufficient to cause promoted ignition of the metallic parts.

9.4.2 Design recommendations

All parts must be approved for use in oxygen, even those which may be in contact with the oxygen in case of leak. The dielectric material shall also be non-permeable to gaseous oxygen.

Since insulating joints are subject to stresses due to underground piping deformations, it is recommended to over-design them[9] and to perform hydraulic testing of the one piece type twice the maximum working pressure.[10]

Preferred type is with enameled CS (or enameled Copper ring) (or fully oxidized material ring), smooth protruding and O ring gaskets.



The dielectric strength of insulating joint shall not be less than 5 kV.

[9] This leads to selecting a higher flange rating for the flange type

[10] Testing is not prescribed for the flange type because it is not feasible

A differential voltage limitation device (polarization cell or dry capacitor), (typically 10 volts) must protect the insulating joint against high voltage (lighting, electrical line failure…) in order to avoid ignition by arcing.

9.5 METERS

9.5.1 GENERAL

There are two categories of metering systems:

- Stationary element meters (orifices, Venturi, Pitot Tube, ultrasonic or Coriolis)
- Moving element meters (turbine, positive displacement meters) allow broader range and better accuracy.

Note: The use of a "hot-wire" flow measurement device needs a specific study and, in any case, is not recommended for pressures above 3 bar g.

9.5.2 IGNITION MECHANISMS

Static meters are subject to particle impact only.

Meters with moving parts are also subject to friction. They are sensitive to over-pressure, over-speed, reverse flow, and wear.

9.5.3 DESIGN RECOMMENDATIONS

9.5.3.1 Moving element meters

They are to be avoided. They are prohibited above 3 bar g. Below 3 bar g, they must be protected against over speed and require a specific analysis.

9.5.3.2 Stationary element meters

Impingement parts must be made of combustion resistant material. No specific filtration is required.

At this stage, the DANIEL Senior Orifice Fittings (orifice plate replaceable during operation) are not recommended.

9.6 THERMOWELL

Thermowells experience direct impingement flow.

Free passage around the thermowell must be sufficient to maintain the oxygen velocity within the limitation curves (refer to section 7).

Thermowells are to be made of stainless steel or combustion resistant material.

9.7 OTHER INSTRUMENTATION COMPONENTS

As these lines have got small diameter (typically less than 10 mm), low velocity, and considering the experience accumulated, it is possible to accept the use of stainless steel above its exemption pressure.

Instrument lines shall be in stainless steel or better up to 200 bar.

Any other instrumentation accessories such as pressure sensor, pneumatic control devices, instrument manifold valves… which may come in contact with oxygen shall be constructed from stainless steel or better and oxygen compatible non metallic materials. Particle accumulation locations should be avoided.

All pressure sensors and indicators should be clearly marked for oxygen service ("Oxygen service, no oil, nor grease").

Using calibration devices that introduce oil into the instrument is forbidden.

9.8 SILENCERS

9.8.1 IN LINE NOISE ATTENUATION DEVICES

These devices consist of perforated plate(s).

They are impingement area. They should be made of combustion resistant material at the upstream pressure (thickness to be taken into account).

Diffusers (either perforated attenuation plates or cylinders) shall be made of combustion resistant material at the inlet pressure. Depending on the design (valve, piping and diffuser), this pressure can be as high as the upstream pressure of the control valve.

Sufficient distance between the diffuser holes and the shell must be provided in order to allow sufficient velocity head reduction (typically 20 hole diameters). When the local pressure is below 3 bar g, carbon steel can be used.

The remaining components (baffles: containing plates of the sound absorbing materials, supports…) of the silencer have to be made of combustion resistant materials at the total pressure inside the silencer. They shall be non greasy and non combustible, such as fiber glass or mineral wool.

Atmospheric silencers use stainless steel typically 1 mm thick for perforated containing plates (corrosion).

Note: the above material requirements limit their use to very low pressure for economical reason.

9.9 MISCELLANEOUS

Pipeline systems and stations should avoid the use of bursting discs (flow not interruptible).

The use of permanent flexible connection, hose and expansion joint is not recommended due to their thin thickness and their design involving possible dust trap locations. *If bellows are used to connect compressor to a pipeline, they should be installed inside the compressor barriers.*

Flexible piping components must be validated (see APPENDIX D).

10 PIPE AND FITTINGS DESIGN AND VALIDATION

10.1 PIPE

10.1.1 Ignition mechanisms

The uniform sections of pipes (including long radius bends R > 5 D) are not ignition starting points, but they can be ignited by upstream and even downstream fires. They are not considered as risk areas provided that they follow the proven practices.

10.1.2 Design recommendations

Pipe and fittings purchased for an oxygen piping system should always be free of rust, with no internal paint, varnish or non metallic coating . All components are to be stored in a suitable place (avoid any contamination by oil or other organic material), and cleaned according to procedures prior to their use (see section 13.1 here after).
The use of non-metallic rigid pipes is forbidden for oxygen.

10.2 ELBOWS AND MITERED ELBOWS

10.2.1 Ignition mechanisms

Ignition may occur in elbows due to impingement of particles flying (travelling) from upstream during flow or pressure changes. These particles can be either inert particles or burning particles ignited in upstream impingement areas. Therefore, elbows should be considered as potential ignition starting points.

10.2.2 Design recommendations

Short radius elbows (1D) are not allowed.

Standard "long radius" 1.5 D are commonly used.

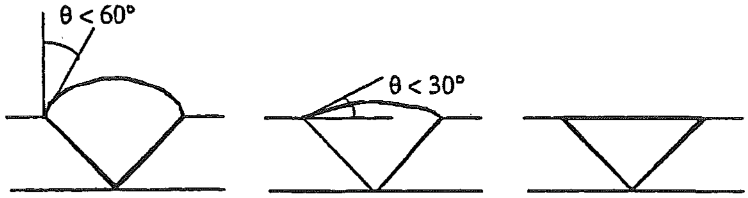
An elbow can be exposed to particle impact ignition in three cases:

- Due to higher velocity than the velocity limit with the normal dust content (covered by velocity limitation)
- Due to abnormal dust load with normal velocity (taken care of by filtration level)
- Due to previous ignition of entrained particles (short distance with regard to the preceding ignition area, i.e. shorter than 20D)

In the case of a short distance with respect to a preceding potential particle ignition component (for instance combustion resistant throttling valve or elbow) the downstream elbow must be made of a combustion resistant material or an exemption material (see section 9.2.2.2). The pipe downstream the elbow must also be made of the same material for 8D. If the following elbow is within 5 meters from a personnel presence location or 20D from the previous elbow then it must also be made of combustion resistant material (See APPENDIX F)

A source of accumulated particles is the final water cooler of an oxygen compressor. This should be treated in the barrier design of the compressor (position of the first carbon steel elbow, check valve location...).

The 90° mitered elbows made of 6 pieces (5 welds), as well as the 45° mitered elbows made of 3 pieces (2 welds) are not considered as impingement sites providing that **all internal weld surfaces** are smooth or flush (particles resulting from these operations must be removed).



Rough Smooth Flush

Formed or pressed elbows with sweeping curvatures (whenever available) are preferred over their mitered counterparts in order to reduce impingement.

10.3 FLANGES AND COUPLINGS

10.3.1 IGNITION MECHANISMS

A flange connection may create a dust trap (especially when the pipe is horizontal and the gasket vertical). The particles accumulated may be ignited by differential voltage (electrical arc, lightning, heating by Joule effect when insufficient electrical continuity is provided like insulating joints...).

Flow friction through a leak may also ignite the gasket.

10.3.2 DESIGN RECOMMENDATIONS

A welded or flanged system is recommended.

Slip-on flanges should be avoided, as there is a dust trap whenever the pipe is horizontal.

Threaded end connections are tolerated for small valves (50 mm and below) and instrumentation.

Socket weld end connections are allowed for piping diameters up to DN50 (2 inches).

10.4 GASKETS

10.4.1 IGNITION MECHANISMS

Abnormal local velocities due to leaks may start ignition by local abrasion of the gasket itself and or the contact face.

10.4.2 DESIGN RECOMMENDATIONS

Although asbestos is oxygen compatible, its use for gaskets **is prohibited** for health reasons.

Recommended practice consists in using gaskets made of compatible materials **approved** for use with Oxygen by BAM or AIR LIQUIDE CTE or another laboratory approved by AIR LIQUIDE:

- Flat gaskets: Expanded graphite with S.S or nickel reinforcement (Klinger KGL SLS ; Supranite NG…); PTFE.
  Normal PTFE has a very low compressibility coefficient and must not be used.
  Only special PTFE with a higher compressibility coefficient is to be used and only with stronger flanges (above PN10, 150 lbs).
  It is necessary to well check the parallelism of flanges faces, and to respect the required tightening torque. Excessive torque does not improve tightness, and may warp the flanges (specially with low pressure rate), or increase the risk of PTFE gasket push-out.
- Spiral-wound gaskets: Stainless steel web with amorphous graphite insert and double centering ring.
- Annular metallic gaskets: may be made of soft iron, copper or stainless steel. (iron gaskets are preferable to any non metallic gaskets).

Flat gaskets shall be full-face and ordered to the exact pipe bore. In cases where spiral-wound gaskets have to be used, the inner ring shall be ordered to the exact pipe bore.

10.5 REDUCERS

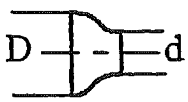
10.5.1 IGNITION MECHANISMS

Ignition may occur in reducers due to impingement of particles flying from upstream during flow or pressure changes.

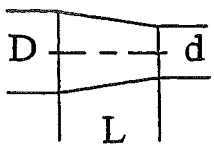
10.5.2 DESIGN RECOMMENDATIONS

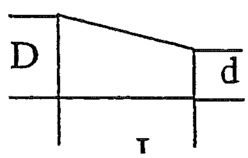
Maximum allowable velocity in reducers is to be considered at the smaller diameter end. The velocity at the small end may impose combustion resistant material.

Commercially available "Bell shaped" (eccentric or concentric) reducers are acceptable provided that d is not smaller than one size below D.



For conical concentric reducers, the length must be greater than 3 times the difference between the great and the small nominal diameter: $L >= 3(D - d)$





For conical eccentric reducers, the length must be greater than 4 times the difference between the great and the small nominal diameter: $L >= 4(D - d)$

These rules do not apply if reducers are made of materials below their exemption pressure.

10.6 TEES

Tees and stub-ins are impingement areas (see section 11.2.5). Consequently they may be required to be made of combustion resistant material depending on velocity.

11 SYSTEM ARCHITECTURE

11.1 GENERAL

Each piece of equipment dictates its own installation safety constraints (as described above). The general architecture results of combining and optimizing these constraints.

11.1.1 IGNITIONS MECHANISMS

As a rule, a piping system consisting of several components is subject to a certain number of ignition mechanisms and sources :

External mechanical aggressions : Shocks, Vibrations, Heat sources, Electric arc and spark...

Leaks can lead to oxygen enrichment of confined areas (pits, trenches, gutters) or to ignition of combustible products (pipe coating, surrounding materials like. asphalt, bitumen, wood, grease, oil, oily waste, and all other organic materials including vegetation).

Flow friction can occur with any leak at flanges or other mechanical connection involving non metallic material (e.g. soft gasket). Care must be taken when performing maintenance work in presence of any potential pressure. Lines in oxygen should never be depressurized or purged by opening a flanged joint.

11.1.2 POTENTIAL CONSEQUENCES

Combustion may take place elsewhere than at the initial ignition site, for instance downstream or outside.

One can say than the magnitude of the consequences is determined by the size of the breach and roughly proportional to $P*d^2$, where "d" is the expected hole diameter and not necessarily the pipe diameter. As a matter of fact, all risk factors are proportional to this value: oxygen flowrate (oxygen enrichment, overpressure), fire intensity, dynamic impulse to large fragments.

11.1.3 PERSONNEL PROTECTION

The personnel protection degree can be considered as a function of the above defined $P*d^2$.
Whenever space is available, suitable distances, combined with remote operation may be a good solution.
If adequate distances cannot be met, protective barriers have to be considered.
Warning and fences should be located accordingly during the construction phase.

11.2 PIPING

11.2.1 ABOVE-GROUND PIPING

It is preferable to route oxygen piping at the edge of the racks for inspection accessibility, protected from any potential impact or vibrations.

Attention must be paid to distance between potential leak sources (e.g. flanges, valves…) when an oxygen pipeline is running near a combustible fluid line.

The pipelines must be protected from accidental impacts of vehicles or handling devices.

Need for appropriate protection must be studied where electrical overhead transmission lines pass over an above-ground oxygen pipeline.

11.2.2 UNDERGROUND PIPING

Underground piping must be externally coated (to an approved specification), to be protected against soil corrosion (see section 13.5).

Due to the possibility of leaks and risk of enriched atmosphere, flanges underground, either buried or in pits, are prohibited.

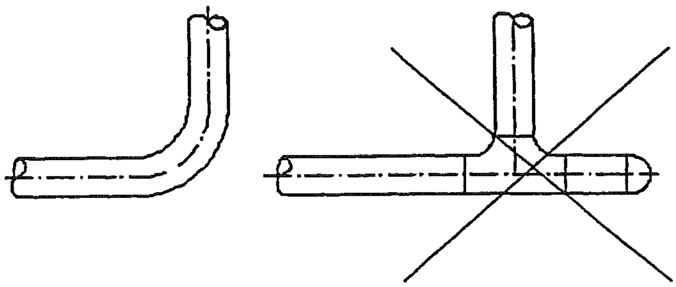
Underground piping should be adequately buried to protect it from frost, future constructions, damage to external surface of pipe or of coating during back filling of the trench or installation, and above ground loads such as vehicles.

No flanges shall be allowed in tunnels or casings.

11.2.3 DEAD ENDS

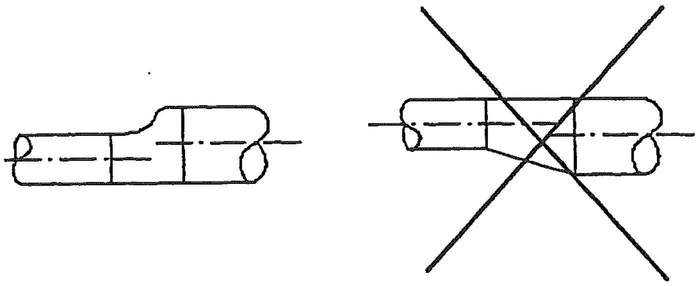
As a rule, dead ends shall be avoided.

Dead ends are to be carefully studied in all possible operational configurations as particles may accumulate, or can form a resonance chamber (especially downstream of let-down valves). In particular, consideration must be given to lines in stand by, as by-pass pipe, vent pipe or purge. (Taps should be installed above the horizontal center line of the main pipe, to avoid any particle deposit in the dead end).



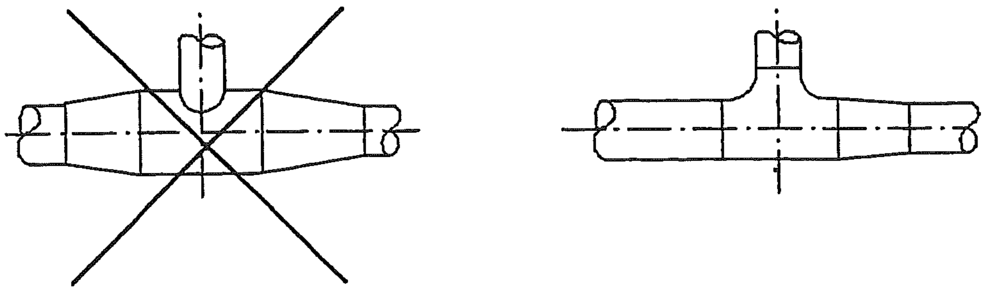
11.2.4 Reducers

When eccentric reducers are used in a horizontal position, it shall be ensured that the straight generating line is at the bottom.



11.2.5 Tees and branch connections

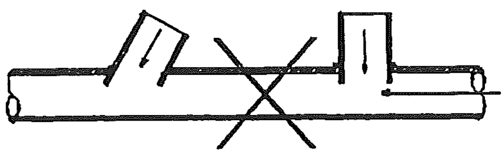
The forming of enlargements of cross section that facilitate accumulation of dust shall be avoided.



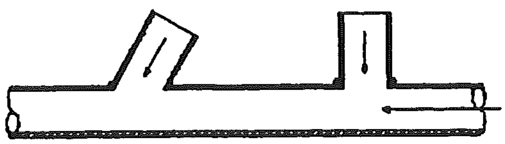
Abrupt discontinuities in the pipe system are undesirable.

Two cases:

- Single material (CS branch on CS main pipe): branch connection shall be internally flushed in order to avoid protruding ends:

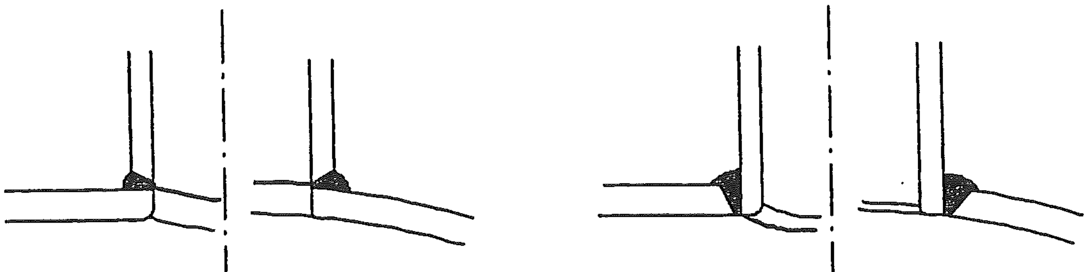


INCORRECT JOINING



CORRECT JOINING

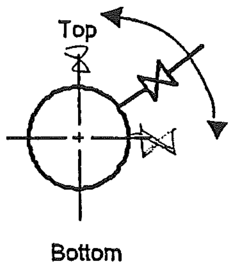
- Branch in combustion resistant material on CS pipe: combustion resistant branches on CS pipe shall be stub-in design (as per ASME.31.3 fig 328.5.4D or fig 328.5.4E), with reinforcing pads or saddles if necessary



(1) recommended for branch in usual material

(2) recommended for branch in exemption material

In horizontal pipelines, upstream and downstream connections for a by-pass valve shall be installed at or



above the horizontal center line of the pipe.

11.2.6 Vents and pressure taps

The pipeline system and stations should have an adequate manual vent valve to allow blow-down and purge.

Vents valves and pressure taps connections shall be installed on the top part of a horizontal pipe.

11.3 VALVES AND SAFETY VALVES

11.3.1 General

Valves should be preferably located above ground, in an open area.

For a length of 8 pipe diameters downstream a throttling valve, the pipe shall be straight and without any process branch connection.

Valves in pits, below ground or in enclosed spaces, should be avoided.

Discharge piping to the atmosphere shall be located outdoors, in a safe area. (refer to AL Design Safety Recommendation DSR-B02.03).

Downstream piping to atmosphere (from the discharge of the vent valve) may be made of carbon steel provided that pressure drop remains substantially lower than 1 bar.

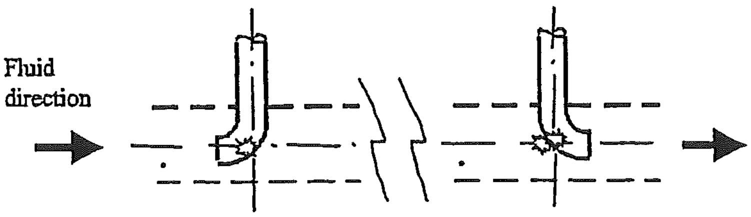
11.3.2 PRESSURE EQUALIZATION

Lines need to be pressurized slowly to minimize the temperature rise due to adiabatic compression (see section 5.2.6). The recommended pressurization rate is 2 bar (30 psi) per minute.

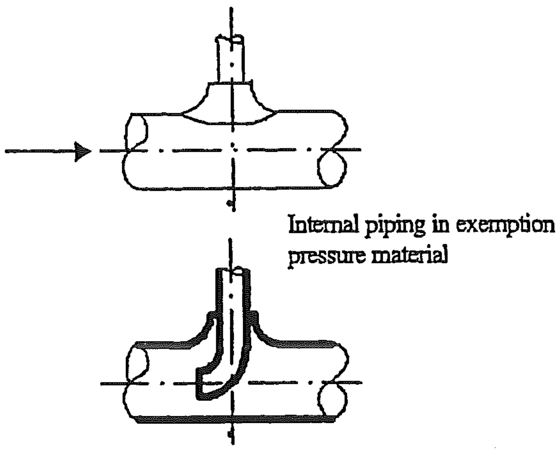
A bypass system may be necessary to perform pressure equalization at this acceptable pressurization rate. The bypass system size may range from DN8 (1/4" NPS) to DN50 (2" NPS). The preferable size for mechanical strength is DN25 (1" NPS) while the maximum size is DN80 (3" NPS).

If the downstream volume is so large that pressure equalization cannot be achieved within an acceptable period via a DN80 (3" NPS) bypass valve, the isolation valve may be used to pressurize the downstream piping, provided that the valve and its associated piping are designed for "throttling service".

The piping upstream and downstream **the bypass valve** shall be designed such as any impingement area is made of combustion resistant material. (See example below).



Impingement areas



11.4 FILTERS

Filters may be installed only where there is no back flow risk through them. (Use of a check valve may be necessary immediately downstream to eliminate this risk).

Filters are generally installed ahead of :

- Any component in the system in which velocity cannot be controlled, but is determined by the pressure drop or activity of the component ;
- Components which have internal moving parts ;
- Components which can create high velocity and thus accelerate particulate material onto wall surfaces in transient conditions.

The inlet diameter should not be reduced with regard to the incoming pipe.

Filters are required upstream of equipment such as pressure regulators, control valves, and moving element meters. The only exception is for Carbon Steel piping of less than 100 meters length downstream a clean section (cold box, backup vaporizer, filter)[11] provided that it has been carefully cleaned and dried during commissioning, and kept dried during operation or after maintenance. (When length is more than 100 m, presence of particles generated by the pipe itself is to be considered).

Areas where dust can accumulate or impingement areas in CS shall be avoided downstream the filter and upstream the throttling valve.

Filters should be provided with inlet and outlet block valves to permit removal for cleaning. If a line cannot be taken out of service for cleaning the filter, parallel filters should be installed, and each should be provided with inlet and outlet block valves.

The vent valve of a filter shall be installed on the filtered gas side, (downstream of the filter, and ahead of the discharge block valve).

Filters should not be equipped with valves for in-service back blowing, since this entrains particles at very high velocity.

Bypass lines around filters to permit flow continuity during filter removal for cleaning are not recommended as a substitute for parallel filters.

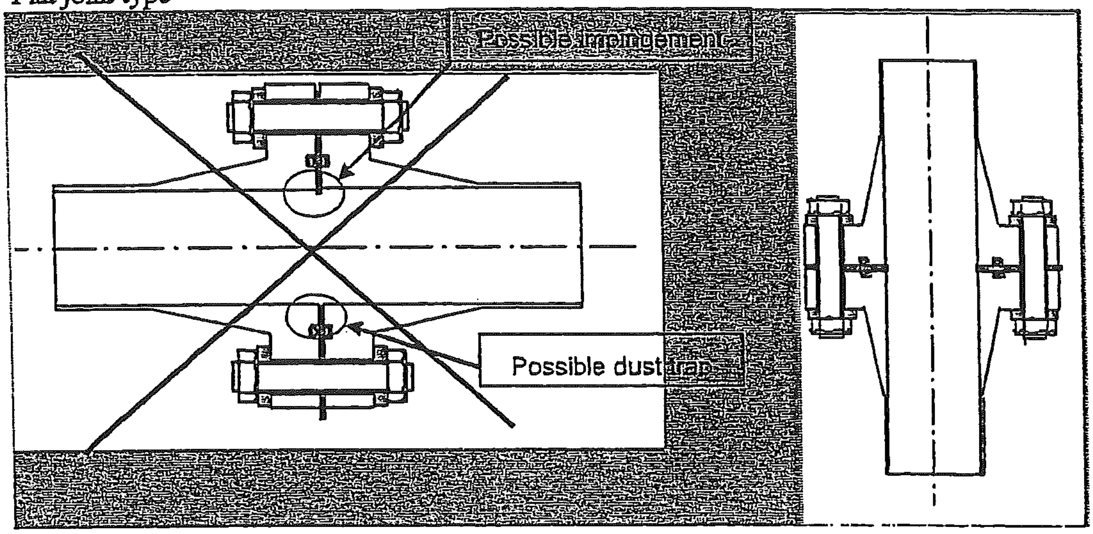
11.5 INSULATING JOINT

Enameled type insulating joint may be installed horizontally provided that the enameled joint is slightly protruding the internal section of pipe.

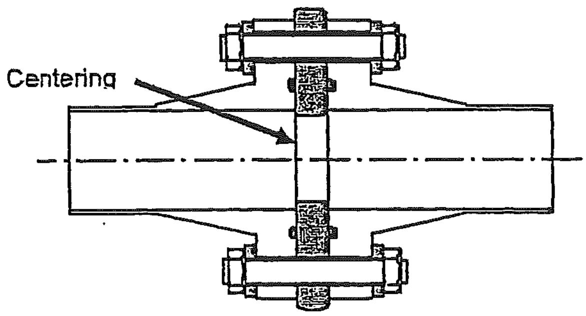
When the design of the insulating joint may be a dust trap (gap between two flanges) installation on a vertical pipe is required.

[11] *The discharge of an oxygen compressor is not considered free of particles.*

Flat joint type



Enameled joint type



11.6 MOVING ELEMENT METERS

Although moving elements type meters are not recommended, they require special safety considerations:

- Piping should be designed and installed to apply minimum stresses on connections
- An inlet filter should be installed directly upstream of meters (refer to §9.3)
- Manual maintenance operation near the meter should be made behind protective barrier unless it is locked isolated or made of non–ferrous material.
- Meter systems should be located remotely from other equipment and piping, preferably outdoors.
- Manual block and bypass valves should be reasonably remote from meters to be located away from any potential fire area or separated by a barrier.

12 PROTECTIVE EQUIPMENT DESIGN

Siting and safety distances should follow the established regulations (NFPA-53, EIGA-13/82 chap.4.2.2.3) and/or internal standards (AL-GR.204.41).

12.1 BARRIER DESIGN CRITERIA

12.1.1 FIRE RESISTANCE

Fire barrier should be made of concrete or equivalent.

This equivalence is given by the following test: the fire barrier shall be capable of completely blocking an oxygen combustion lance of approximately 5000°F (2760°C) for a minimum of 3 seconds with an oxygen lance ¾" diameter from PGE or Oxylance fed with 100 psig minimum and placed at 6 inches (15 cm) from the barrier[12]

12.1.2 BLAST RESISTANCE

The fire barrier should withstand a jet load F calculated by using the following equation:

where F is jet load ; D is pipe diameter ; P is nominal gas pressure (P_{amb} is atmospheric pressure)

$F = 1.017 \times PD^2 - 0.81 \times D^2$ (F in daN; D in cm, and P in bar) abs)

$F = 0.997 \times PD^2 - 11.54 \times D^2$ (F in lbs; D in inch, and P in psi)

Based on the present knowledge, it is considered that a barrier sized according to this formula will also block a fragment resulting from an oxygen equipment fire (except machine fire).

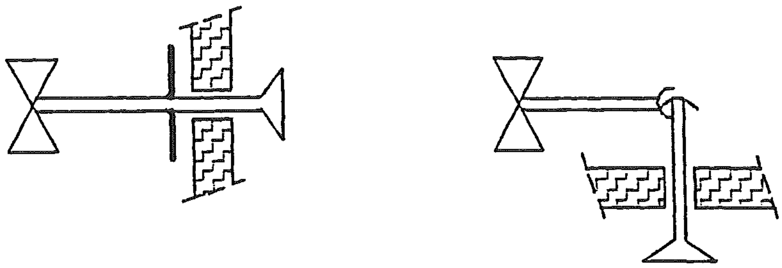
12.2 PERMANENT BARRIERS

Personnel are not allowed to enter the barrier while oxygen is flowing in the piping system.

Appropriate signs must be prominently displayed and installed during the construction phase.

Equipment that shall not be located within protective barriers include: operator controls, instrumentation readouts and equipment whose maintenance must be made during operation, emergency shutdown switches, sampling valves.

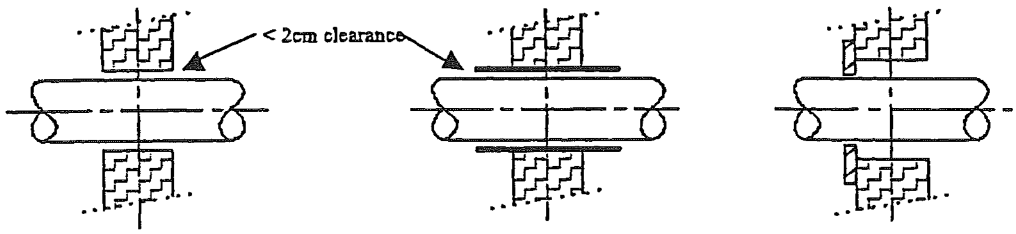
[12] Concrete complies with that condition, or 11 mm thick « Hardie Panel », James Hardie Building Products, Mission Viejo, California USA (indoor service), or ½" thick "Steelstone", AFI, Charlotte, North Carolina USA (indoor/outdoor service), or 10 mm thick DuraSystems "3DF2" sheet with galvanised steel, Durasystems Barriers Inc. Vaughan, Ontario, Canada (indoor/ outdoor service)



Manual valves located within protective barriers, that need to be operated while oxygen is flowing, shall be equipped with an extension wheel and with an angle gear drive or a locking plate welded on the extension.

Its height must be at least 2.5 m and block any line-of-sight view of the equipment from walkways, permanent platforms or public buildings within 15 meters.

The barrier should have no hole except for piping or equipment passing through, but in this case, the maximum clearance should be no greater than 2 cm.



12.3 TRANSPORTABLE

To be developed.

12.4 INDIVIDUAL

Individual protections seem not to be feasible. Only fire retardant clothes are considered but need further validation.

13 SETUP INSTRUCTIONS

13.1 CLEANING

Safe use of oxygen requires the control of potential ignition energy mechanisms within oxygen [(1)] systems by maintaining scrupulously clean systems.
Cleanliness (contamination control) is critical in oxygen components and systems. Contamination can cause ignition of components or systems by a variety of mechanisms, such as particle impact, mechanical or

Minimize the quantity of soft materials. Exposure of soft materials to oxygen may be reduced by shielding them with nickel or copper based alloys.

Metal to metal seals are preferred for high temperatures or pressures, although they are often less leak tight.

Eliminate burrs and avoid sharp edges which are ignition sources for particles impact.

Remember than a part in contact with oxygen on both sides is more subject to ignition.

Throttling valves

Be aware of seat shape and seal design.

Metallic parts to be used under the exemption pressure, taking into account the actual thicknesses of each component.

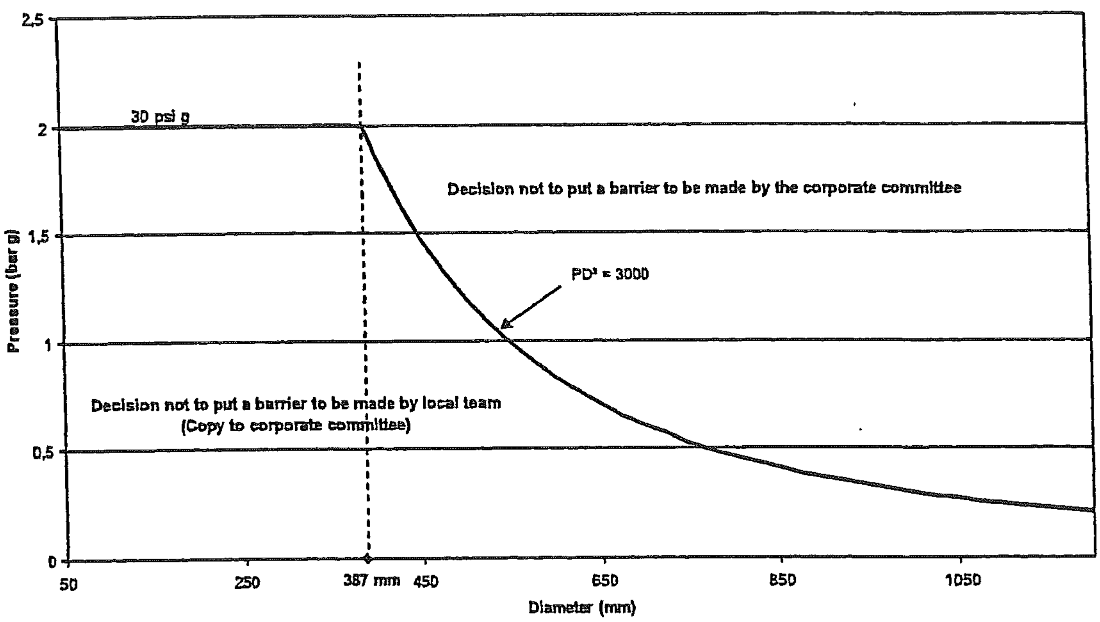
In order to avoid any accumulation of any static charges, check the electrical continuity between all metallic parts.

Check valves

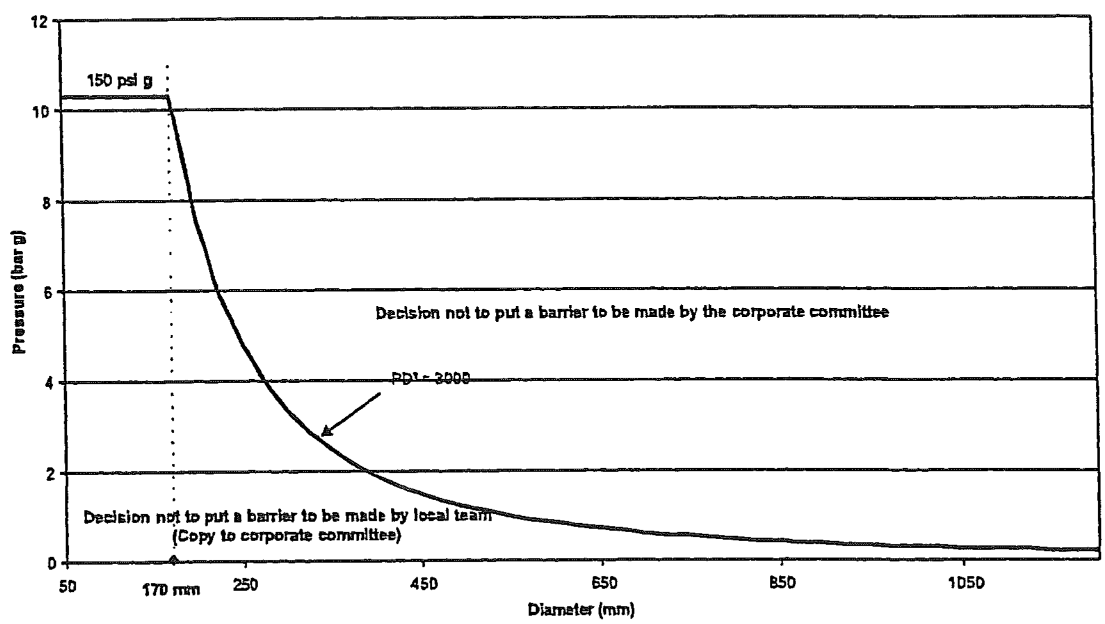
The valve body of a dual-flapper-style check valve is of a design *in the* which a significant portion of the valve body experiences impingement. Check-valve bodies that experience direct impingement flow are essentially treated as though they are throttling valves.

See next pages the validation area for different materials.

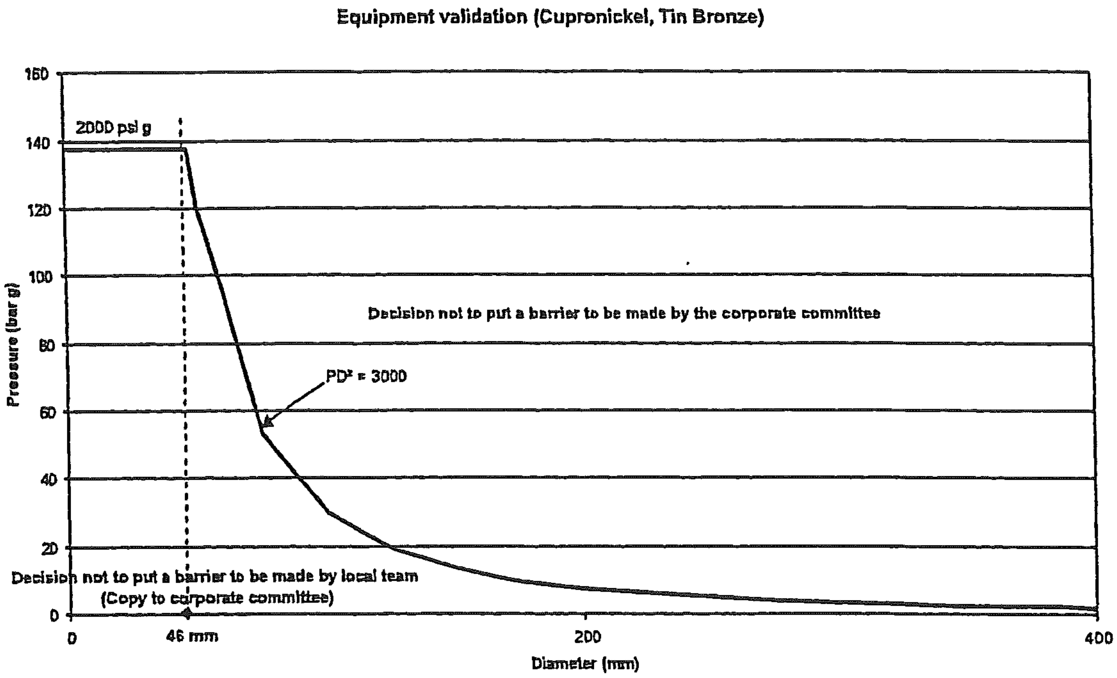
Equipment validation (Carbon Steel)

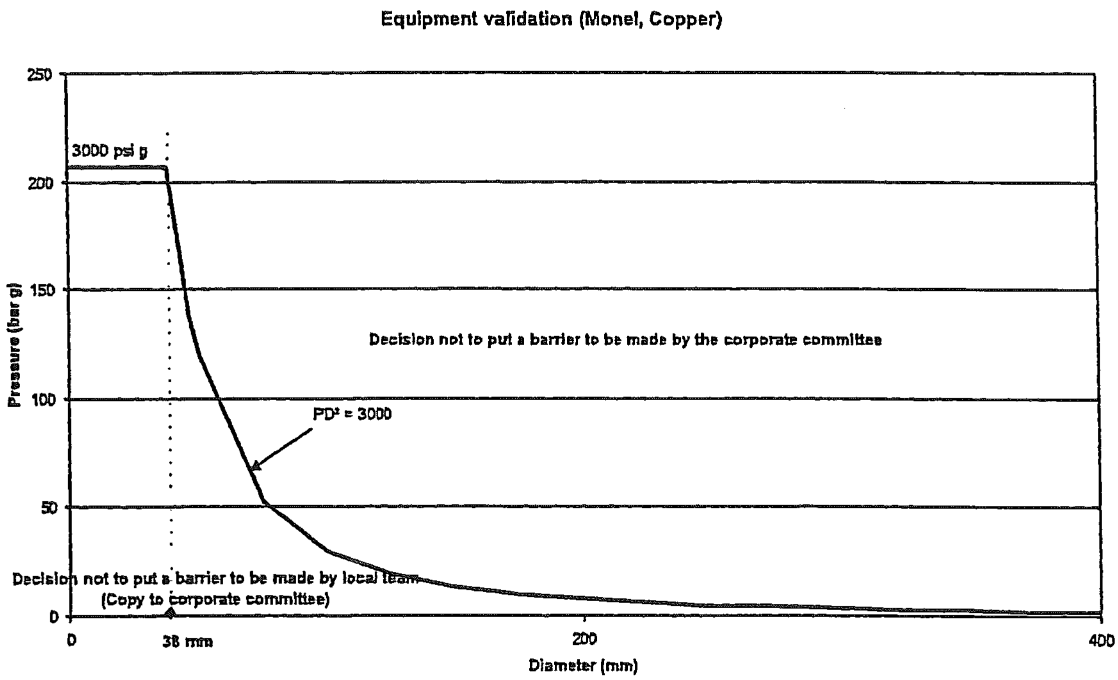


Equipment validation (Stainless Steel)

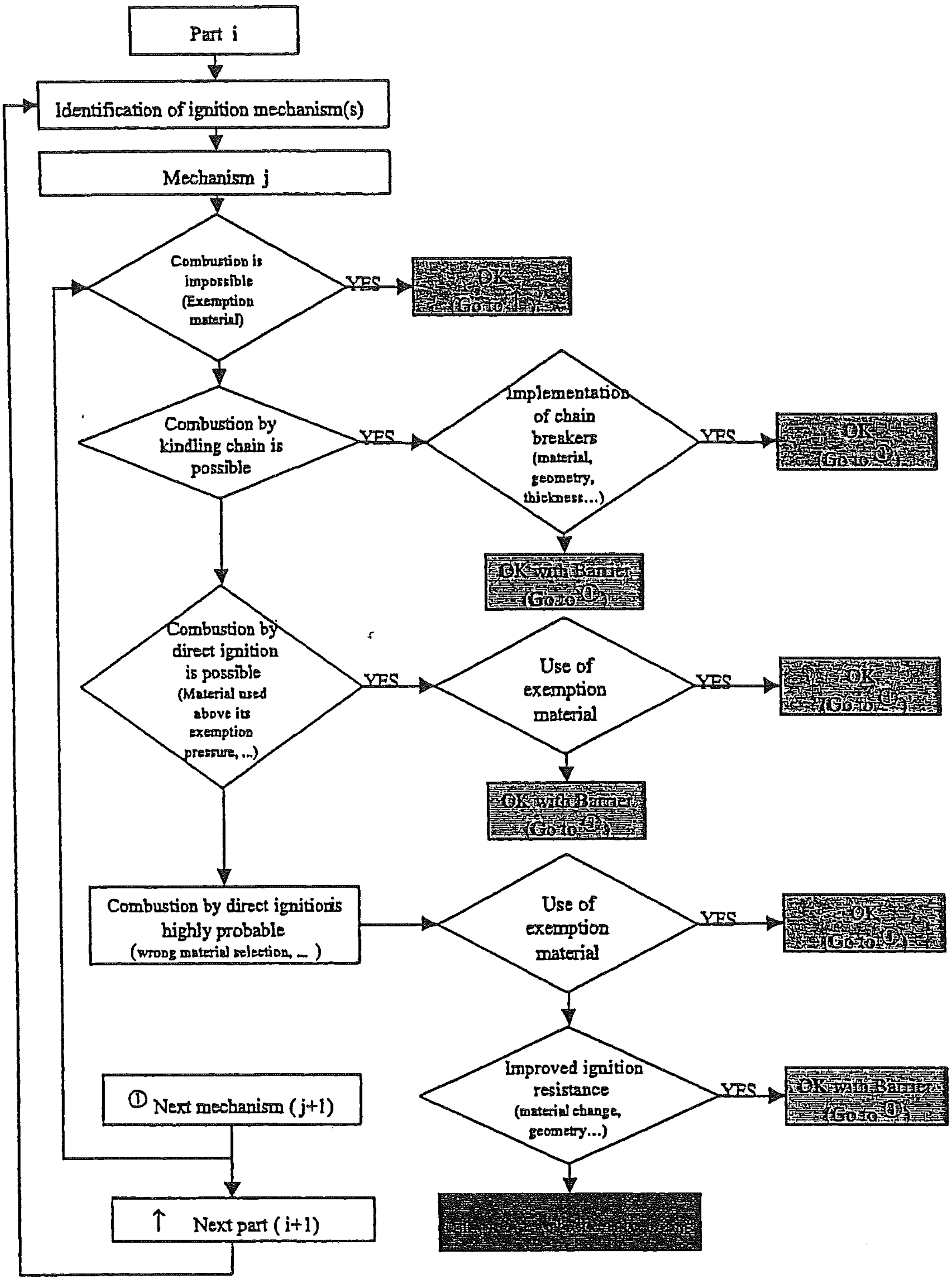


DESIGN REQUIREMENTS FOR GASEOUS OXYGEN PIPING





Flow chart of analytical method for equipment parts

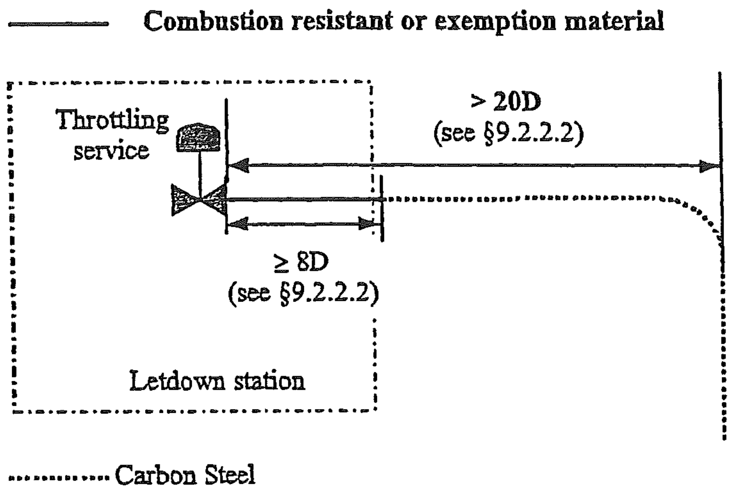


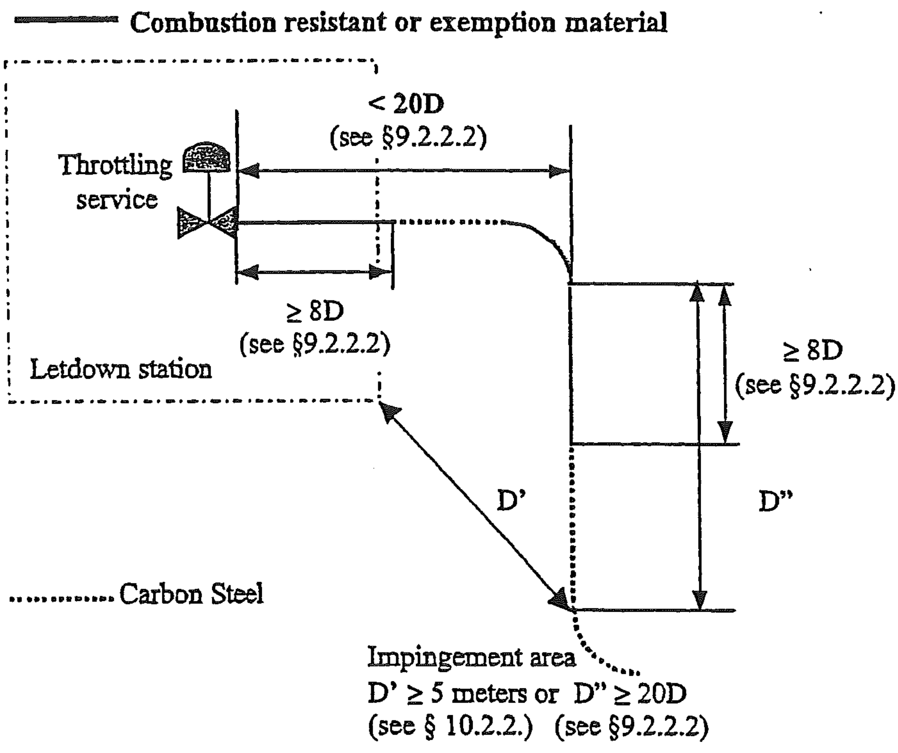
APPENDIX E

French translation of the definitions in chapter 4

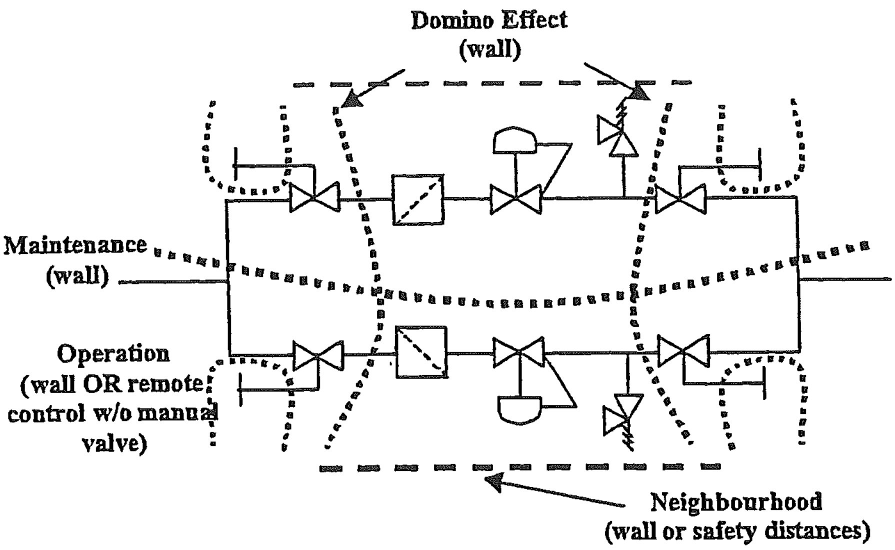
Barrier :	Ecran
Burr:	Bavure
Fire barriers	Ecran anti-feu.
Fragment barriers	Ecran anti-éclats.
Exemption materials	Métaux .compatibles Oxygène
Exemption pressure	Pression d'exemption
Flow friction	Frottement gazeux
Gaseous Oxygen	Oxygène gazeux
Impingement	Impact
Isolation valves	Robinets de sectionnement
Promoted ignition	Inflammation provoquée
Oxygen piping system	Tuyauterie Oxygène
Self contained regulator	Détendeur, déverseur
Stainless Steel	Acier Inoxydable
Soft seat or soft gasket	Siège ou joint en polymères
Threshold pressure	Pression limite
Throttling valves	Robinets de détente
Twill weave	toile REPS
Velocity	Vitesse
Wall	Paroi

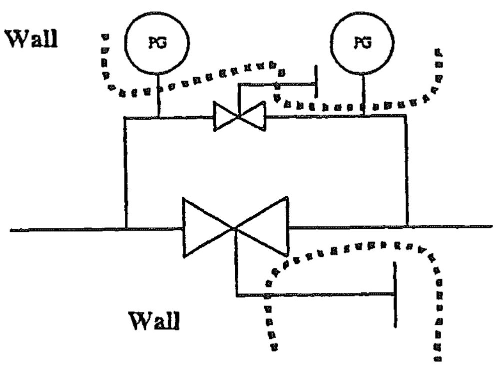
APPENDIX F


Combustion resistant or exemption material
> 20D
(see §9.2.2.2)
Throttling
service
≥ 8D
(see §9.2.2.2)
Letdown station
Carbon Steel


Combustion resistant or exemption material
< 20D
(see §9.2.2.2)
Throttling
service
≥ 8D
(see §9.2.2.2)
Letdown station
≥ 8D
(see §9.2.2.2)
D'
D"
Carbon Steel
Impingement area
D' ≥ 5 meters or D" ≥ 20D
(see § 10.2.2.) (see §9.2.2.2)

APPENDIX G


Domino Effect
(wall)
Maintenance
(wall)
Operation
(wall OR remote
control w/o manual
valve)
Neighbourhood
(wall or safety distances)


Wall
PG
PG
Wall

DESIGN REQUIREMENTS FOR GASEOUS OXYGEN PIPING

Oxygen compatibility of metallic alloys **(Table in bar and mm)**

Material (UNS Number)	**Particle impact**	**Friction Rubbing**	**Promoted Ignition**	Threshold abs pressures bar (3.2mm dia) (6)	EIGA/CGA Exemption pressures bar g (3.2 mm) (6)	AL Exemption Pressures bar g (3.2 mm) (7)
NICKEL 200	-	A	A (2)	> 550	207 (1)	207 (4)
NICHROME V	-	-	A (2)	-	207 (1)	
MONEL 400	A	A	A (2)	> 690	207 (1)	207 (4)
MONEL K500	A	A	A (2)	> 690	207 (1)	207 (4)
NAVAL BRASS (C46400)	-	-	A (2)	> 690	207 (1)	
COPPER			A (2)	> 550	207 (1)	207 (4)
90-10 CUPRONICKEL (C70600)	-	-	A (2)	-	207 (1)	138
70-30 CUPRONICKEL (C71500)	-	-	A (2)	-	207 (1)	138
FREE CUTTING BRASS (C36000)	-	-	A (2)	-	138 (1)	
BERYLLIUM NICKEL	-	-	A (2)	-	-	
2% BERYLLIUM COPPER (C17200)	-	-	A (2)	> 690	138 (1)	
ADMIRALTY BRASS (C44300)	-	-	A (2)	-	138 (1)	
RED BRASS	-	-	A (2)	> 480	138 (1)	
TIN BRONZE (Gun Metal)	A	A	A (2)	> 480	207 (1)	138 (4)
YELLOW BRASS	A	B	A (2)	> 480	138 (1)	
INCO 141 (Filler metal)	-	-	B	-	-	
INCONEL X750	-	-	B	-	69 (1)	
INCONEL 600	A	A	B	172	69 (1)	
BERYLCO 440	-	-	B	-	-	
SILICON BRONZE (C65500)	-	-	B	-	-	
HASTELLOY C-276	-	B	B	207	51.7 (1)	
STELLITE 6-B	-	C	B	172	34.5 (1)	
MP 35 N	-	-	B	-	-	
INCONEL 625	B	-	B	-	86.2	
INCOLOY 800	B	-	B	172	51.7 (3)	
INCONEL 718	B	-	B / C	69	34.5 (3)	
HASTELLOY X ; G3 ; G30 & B	-	B	B	-	34.5 (3)	
CN-7M	-	-	C	-	375	
CF 3 ; 3M ; 8 ; 8M ; CG-8M	-	-	C	-	14	
17-4 PH STEEL	-	B	C	69	21	
Ni Resist Type D2	-	-	C	-	20.7	
410 SS	-	C	C	-	17.2	10.3
430 SS	-	-	C	-	17.2	10.3
13-4 SS	C	A	-	-	17.2	10.3
316 SS / 316 L	C	C	C	34.5	14-20 (2)	10.3
321 / 347 SS	-	-	C	69	13.8	10.3
304 / 304 L SS	C	C	C	69	14-20 (2)	10.3
INVAR 36	B	C	C	< 69	-	
9% Al BRONZE (C95800)	A	C	C	17.2	10.3 (3)	
Nodular CAST IRON	B	A	C	-	3.5	
NITRONIC 60	C	C	C	< 34.5	-	
14-5 SS	C	B	C	-	-	
9% Ni STEEL	-	C	D	< 34.5	1.7 (3)	

CARBON STEEL		C	D	< 345	2.07	2
6061 ALUMINIUM Alloy	D	D	D	1.7	1.0 (3)	

Notes: see Table in section 6.2.1

AIR LIQUIDE ENGINEERING TECHNICAL COMMISSION	DESIGN SAFETY RECOMMENDATION	DSR B.02.04 (0) Page : 61/62

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